SPECIFICATION

METHOD FOR PRODUCING ELECTRIC POWER STEERING
APPARATUS

6   This application is the national phase under 35 U.S.C. §371 of
7 PCT International Application No. PCT/JP2005/002469 which has
8 an International filing date of February 17, 2005 and designated the
9 United States of America.

TECHNICAL FIELD
       The present invention relates to a method for producing an
electric power steering apparatus that assists the driver to steer a
vehicle by transmitting the drive power of a motor via gears to a
steering shaft equipped with a steering wheel on the upper side
thereof.

BACKGROUND ART
       In an electric power steering apparatus, the drive power of a
motor is transmitted at reduced speed via a small gear provided on
the output shaft of the motor and a large gear meshed with the
small gear to a steering shaft provided with the large gear, and the
rotating motion of the steering shaft is assisted. As the small gear
and the large gear, spur gears, helical gears or the like, having
power transmission efficiency higher than that of a worm gear, are
used to make the electric power steering apparatus compact
(Japanese Utility Model Application Laid-open No. 62-144773
(1987)). By the use of such gears having high power transmission
efficiency, the output of the motor, required for assisting steering
operation, can be reduced, and the motor can be made compact. In
the case that spur gears or the like are used, the steering shaft is
nearly parallel with the output shaft.
       In recent years, for the purpose of making the electric power
steering apparatus more compact, an electric power steering
apparatus comprising gears based on a special theory has been
proposed, in which one set of gears is used, and the large gear
thereof is made as small as possible while the speed reduction ratio
required for assisting steering operation is maintained and while the
gear strength applicable to practical use can be obtained securely
(Japanese Patent Application Laid-open No. 11-124045 (1999)). The
gears based on the special theory are gears in which the curvature of
the tooth profile curve is a continuous differentiable function and

1   changes periodically in the direction of the tooth depth.

2   In the electric power steering apparatus comprising the gears
3   based on the special theory, for the purpose of securely obtaining the
4   gear strength applicable to practical use, it is necessary to
5   accurately process the gears and to accurately maintain the center
6   distance between the gears accommodated in the housing.

7   In addition, for the purpose of smoothly rotating the gears, it
8   is necessary to provide appropriate backlash between the tooth
9   faces. In other words, if the backlash is too large, the problem of
10   backlash noise, that is, large meshing noise due to the collision of
11   the tooth faces, is caused; if the backlash is too small, the problem of
12   unsmooth gear rotation is caused. For the purpose of solving these
13   problems, it is necessary to maintain the center distance between
14   the gears accommodated in the housing constant.

15   Conventionally, these problems are solved by accommodating
16   the steering shaft and the output shaft in the same housing, by
17   fitting a guide plate provided with two holes spaced by a
18   predetermined distance on the steering shaft and the output shaft,
19   thereby maintaining the steering shaft and the output shaft in
20   nearly parallel with each other.

21   More specifically, first, the steering shaft is accommodated in
22   the housing via two roller bearings, and the motor and the output
23   shaft are accommodated in the housing so that the steering shaft
24   and the output shaft are in nearly parallel with each other. At this
25   stage, the center distance between the large gear provided on the
26   steering shaft and the small gear provided on the output shaft is not
27   accurately constant. Next, the steering shaft is rotatably fitted into
28   one hole provided in the guide plate, and the output shaft of the
29   motor is rotatably fitted into the other hole. Furthermore, a C-ring
30   is mounted on the output shaft or the steering shaft so that the
31   guide plate is positioned at the end of the output shaft. Even if the
32   guide plate is subjected to a force acting to move it in the axial
33   direction, the C-ring serves as a stopper, whereby the guide plate is
34   not moved along the output shaft or dropped from the end of the
35   output shaft.

36   In the electric power steering apparatus being produced as
37   described above, the center distance between the large gear and the
38   small gear can be maintained accurately. In other words, the center
39   distance between the gears can be maintained constant in the range
40   of the dimensional errors of the two holes provided in the guide
41   plate; therefore, the gear strength applicable to practical use can be
42   obtained securely, and the problem of backlash noise can be solved.

1   However, in the conventional configuration, in the case that
2   the electric power steering apparatus is used for a long time, the
3   center distance between the gears cannot be maintained accurately,
4   thereby causing problems of being unable to securely obtain
5   sufficient gear strength and being unable to maintain appropriate
6   backlash between the gears. In other words, in the conventional
7   configuration, the walls of the holes provided in the guide plate are
8   in the state of making tight contact with the output shaft and the
9   steering shaft to accurately maintain the center distance between
10   the gears; in the case that the electric power steering apparatus is
11   used for a long time in this state, the walls of the holes are
12   inevitably worn and deformed owing to the rotation of the steering
13   shaft and the output shaft. Hence, the center distance between the
14   large gear and the small gear cannot be maintained accurately
15   owing to the abrasion of the walls of the holes, and the gear strength
16   assumed in the design stage cannot be maintained. Furthermore,
17   because of the same reason, the backlash between the gears cannot
18   be maintained appropriately.
19   Moreover, because the gears based on the special theory have
20   special tooth face profile, problems are caused, that is, the gears
21   cannot be processed using existing general-purpose machines, and
22   the process accuracy of the gears cannot be inspected efficiently.
23
24 DISCLOSURE OF THE INVENTION
25   In view of the above-mentioned circumstances, an object of the
26   present invention is to provide a method for producing an electric
27   power steering apparatus capable of maintaining the center distance
28   between the large gear and the small gear constant and securely
29   obtaining sufficient gear strength of the gears and appropriate
30   backlash between the gears, and also capable of maintaining the
31   sufficient gear strength of the gears and the appropriate backlash
32   between the gears even if the electric power steering apparatus is
33   used for a long time.
34   In addition, another object of the present invention is to
35   provide a method for producing an electric power steering apparatus
36   capable of attaining a predetermined speed reduction ratio and
37   securely obtaining sufficient gear strength using a simple structure
38   even in the case that the apparatus comprises a pair of spur gears or
39   helical gears.
40   The method for producing the electric power steering
41   apparatus according to the present invention is a method for
42   producing an electric power steering apparatus assisting steering by

1 transmitting the drive power of a motor via a small gear provided on
2 the output shaft of the motor and a large gear meshed with the
3 small gear to a steering shaft provided with the large gear, and
4 comprising first and second housings accommodating the steering
5 shaft and the output shaft, the second housing being mounted on the
6 first housing, characterized in that the second housing is
7 temporarily mounted on the first housing in the state that the
8 mounting position of the second housing with respect to the first
9 housing is aligned at a predetermined position using positioning
10 means that aligns the second housing at the predetermined position;
11 that steering shaft supporting sections that support the steering
12 shaft and output shaft supporting sections that support the output
13 shaft in nearly parallel with the steering shaft are provided for the
14 first housing and the second housing respectively; that the second
15 housing is removed from the first housing; that the steering shaft
16 and the output shaft are supported using the steering shaft
17 supporting sections and the output shaft supporting sections via
18 bearings; and that the second housing is mounted on the first
19 housing by aligning the second housing at the predetermined
20 position using the positioning means.
21   With the present invention, because the mounting position of
22 the second housing with respect to the first housing can be aligned
23 at the predetermined position using the positioning means, even if
24 the second housing is removed from the first housing so that the
25 steering shaft and the output shaft are accommodated in the
26 respective housings after the second housing was mounted in the
27 first housing in the state of being aligned at the predetermined
28 position and the steering shaft supporting sections and the output
29 shaft supporting sections were provided for the first housing and the
30 second housing respectively, the second housing can be mounted on
31 the first housing by aligning the relative position of the second
32 housing with respect to the first housing at the predetermined
33 position using the positioning means again. Hence, the center
34 distance between the gears is maintained constant in the range of
35 the dimensional errors of the steering shaft supporting sections, the
36 output shaft supporting sections and the respective bearings and in
37 the range of the mounting position accuracy of the positioning
38 means.
39   Furthermore, because the steering shaft and the output shaft
40 of the motor are supported using the steering shaft supporting
41 sections and the output shaft supporting sections via the bearings,
42 the steering shaft supporting sections or the output shaft supporting

1 sections are not worn by the rotation of the steering shaft and the
2 output shaft, whereby the center distance between the steering shaft
3 and the output shaft can be maintained accurately.
4   The method for producing the electric power steering
5 apparatus according to the present invention is characterized in that
6 the positioning means comprises two sets of pin holes provided in
7 the first housing and the second housing respectively and two pins
8 to be engaged with the pin holes.
9   With the present invention, the mounting position of the
10 second housing with respect to the first housing can be aligned at
11 the predetermined position by aligning the second housing with the
12 first housing and by engaging the two pins with the two sets of pin
13 holes provided in the first and second housings. The predetermined
14 position is a position determined by the positions of the two sets of
15 pin holes. The second housing can be aligned with the first housing
16 with higher position accuracy using the positioning means than the
17 case of mounting the second housing on the first housing by merely
18 using screws. In other words, the second housing can be positioned
19 on the first housing in the range of the dimensional errors of the two
20 sets of pin holes and the dimensional errors of the two pins engaged
21 with the pin holes. Because the position alignment of the mounting
22 position of the second housing with respect to the first housing is the
23 position alignment on a two-dimensional plane, the position
24 alignment can be attained sufficiently using the two sets of pin holes
25 and the two pins.
26   The method for producing the electric power steering
27 apparatus according to the present invention is characterized in that
28 the pin holes are tapered holes, and the pins are tapered pins.
29   With the present invention, the second housing can be aligned
30 with the first housing with higher position accuracy by engaging the
31 two tapered pins with the two sets of pin holes serving as tapered
32 holes than the case of carrying out positioning using other pins, such
33 as parallel pins.
34   The method for producing the electric power steering
35 apparatus according to the present invention is characterized in that
36 the center distance between the output shaft and the steering shaft
37 is 35 mm or more and 85 mm or less; in the small gear, the number
38 of teeth is 6 or more and 15 or less, the module is 0.8 or more and 1.5
39 or less, the tooth depth is 2.4 times the module or less, the pressure
40 angle is 20 degrees or more and 27 degrees or less, and the helix
41 angle is 20 degrees or more and 40 degrees or less; and the tooth
42 profile of one or both of the small gear and the large gear is formed

1 so that the pressure angle increases in the direction from the
2 addendum to the deddendum of the gear, and an involute gear
3 subjected to crowning in the tooth trace direction is used for one or
4 both of the small gear and the large gear.
5   With the present invention, because of the above-mentioned
6 specifications and dimensions, appropriate values can be obtained
7 securely for the trochoid interference clearance, the tooth thickness
8 at the addendum and the tooth face stress even in the case of using
9 gears that can be produced using ordinary production processes,
10 without using the tooth profile based on the predetermined special
11 theory.
12   In addition, by the use of the involute gear, the tooth profile of
13 which is formed so that the pressure angle increases in the direction
14 from the addendum to the deddendum of the gear, the stress applied
15 to the deddendum at the maximum torque load can be reduced, and
16 the durability of the gear can be obtained securely.
17   Furthermore, by the use of the involute helical gear subjected
18 to crowning in the tooth trace direction, the tooth face stress is
19 reduced. Hence, even if continuous operation is carried out under
20 the rated load conditions, the durability of the gear can be obtained
21 securely.
22   With the present invention, the gear strength and appropriate
23 backlash assumed in the design of the gear can be obtained securely
24 in the assembly process of the electric power steering apparatus;
25 hence, even if the electric power steering apparatus is used for a
26 long time, the above-mentioned gear strength and appropriate
27 backlash can be maintained.
28   In addition, with the present invention, the second housing
29 can be mounted easily on the first housing with high mounting
30 position accuracy.
31   Furthermore, with the present invention, the large gear and
32 the small gear can be made compact, and the gear strength
33 applicable to practical use can be obtained securely for a long time.
34   Moreover, with the present invention, the second housing can
35 be mounted on the first housing with higher position accuracy than
36 the case of carrying out positioning the second housing on the first
37 housing using parallel pins or the like.
38   Still further, because of the above-mentioned specifications
39 and dimensions, appropriate values can be obtained securely for the
40 trochoid interference clearance, the tooth thickness at the addendum
41 and the tooth face stress without using the tooth profile based on the
42 predetermined special theory.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a sectional view schematically showing the main sections of an electric power steering apparatus that is produced using a method according to the present invention, as seen from the side of a vehicle;

FIG. 2 is an exploded perspective view schematically showing the main sections of the electric power steering apparatus that is produced using the method according to the present invention, as seen from the side of the vehicle;

FIGS. 3(a) and 3(b) are sectional views of the main sections schematically showing processes for providing steering shaft supporting sections and output shaft supporting sections in first housing and the second housing respectively;

FIGS. 4(a) and 4(b) are sectional views of the main sections schematically showing processes for supporting a steering shaft and an output shaft using the steering shaft supporting sections and the output shaft supporting sections via bearings;

FIGS. 5(a) and 5(b) are sectional views of the main sections schematically showing processes for aligning the second housing with the first housing at a predetermined position using positioning means and for mounting the second housing;

FIG. 6 is a graph showing the relationship between the number of teeth of a small gear and the module of the small gear;

FIG. 7 is a graph showing the relationship among the pressure angle, the trochoid interference clearance and the tooth thickness at the addendum of the small gear;

FIG. 8 is a graph showing the relationship of the tooth face stress and the tooth thickness at addendum depending on the tooth depth of the small gear; and

FIG. 9 is an explanatory view showing the tooth face profile of a gear being used for the electric power steering apparatus according to the embodiments of the present invention.

EXPLANATIONS OF NUMERALS

1 first housing
2 second housing
3 steering shaft
4 output shaft
5a, 5b pins (positioning means)
7, 8, 9a, 9b bearings
10, 20 steering shaft supporting sections

1	11, 21 output shaft supporting sections
2	12a, 12b pin holes (positioning means)
3	22a, 22b pin holes (positioning means)
4	30 large gear
5	33 steering wheel
6	40 small gear
7	41 motor
8	h tooth depth
9	m module
10	L center distance
11	Z number of teeth
12	α pressure angle
13	β helix angle
14	

15 BEST MODES FOR CARRYING OUT THE INVENTION
16   (Embodiment 1)
17   The present invention will be described below in detail on the
18 basis of the drawings showing the embodiments thereof.
19   FIGS. 1 and 2 are a sectional view and an exploded
20 perspective view, respectively, schematically showing the main
21 sections of an electric power steering apparatus that is produced
22 using a method according to the present invention, as seen from the
23 side of a vehicle. In the figures, numeral 3 designates a cylindrical
24 steering shaft, on the outer circumference of which a large gear 30 is
25 pressure-fitted, and the steering shaft 3 is rotatably accommodated
26 in a first housing 1 and a second housing 2 so that the axial
27 direction thereof is vertical. The steering shaft 3 is connected to a
28 column shaft 32 equipped with a steering wheel 33 on the upper side
29 thereof via a torsion bar 31 made of an elastic material and fitted in
30 and secured to the steering shaft 3. In addition, the steering shaft 3
31 is equipped with a universal joint (not shown) at the lower end
32 thereof, and connected to a rack-and-pinion steering mechanism, for
33 example, via the universal joint. The large gear 30 is a spur gear
34 and is rotatably accommodated in the first housing 1 and the second
35 housing 2 so as to be meshed in parallel with a small gear 40 serving
36 as a spur gear mounted on the output shaft 4 of a motor 41 and so
37 that the output shaft 4 is nearly parallel with the steering shaft 3.
38 The main body of the motor 41 equipped with the output shaft 4 is
39 mounted in the first housing 1. Steering shaft supporting sections
40 10 and 20 for supporting the steering shaft 3 and output shaft
41 supporting sections 11 and 21 for supporting the output shaft 4 are
42 provided in the first and second housings 1 and 2, respectively, and

1   the steering shaft 3 and the output shaft 4 are supported using the
2   steering shaft supporting sections 10 and 20 and the output shaft
3   supporting sections 11 and 21 via bearings 7, 8, 9a and 9b, such as
4   roller bearings.
5   The second housing 2 is mounted such that the mounting
6   position of the second housing 2 with respect to the first housing 1 is
7   set at a predetermined position using positioning means. In this
8   embodiment, two pins 5a and 5b are engaged with two sets of pin
9   holes 12a, 22a, 12b and 22b provided in the first housing 1 and the
10   second housing 2, respectively, whereby the mounting position of the
11   second housing 2 with respect to the first housing 1 is aligned at the
12   predetermined position (see FIG. 2). In other words, the pin hole
13   12a, one of the pin holes provided in the first housing 1, is aligned
14   with the pin hole 22a that is provided in the second housing 2 and
15   corresponds to the pin hole 12a, and the pin 5a is engaged with one
16   set of pin holes 12a and 22a, whereby positioning is done at one
17   point. Furthermore, the other pin hole 12b provided in the first
18   housing 1 is aligned with the pin hole 22b that is provided in the
19   second housing 2 and corresponds to the pin hole 12b, and the pin 5b
20   is engaged with one set of pin holes 12b and 22b, whereby the
21   mounting position of the second housing 2 with respect to the first
22   housing 1 is aligned at the predetermined position.
23   In the electric power steering apparatus configured as
24   described above, the rotation of the steering wheel 33 turned by the
25   driver is transmitted to the steering mechanism via the steering
26   shaft 3, and the vehicle is steered. On the other hand, the rotation
27   of the motor 41 is transmitted at reduced speed as the rotating
28   motion of the steering shaft 3 via the small gear 40 and the large
29   gear 30, and the steering operation by the driver is assisted by the
30   transmitted drive power of the motor 41.
31   Next, a method for producing the electric power steering
32   apparatus according to the present invention will be described.
33   FIGS. 3(a) and 3(b) are sectional views of the main sections
34   schematically showing processes for providing the steering shaft
35   supporting sections 10 and 20 and the output shaft supporting
36   sections 11 and 21 in the first housing 1 and the second housing 2
37   respectively. The lower view is a sectional view taken on line III-III
38   of the upper view.
39   First, in the state that the mounting position of the second
40   housing 2 with respect to the first housing 1 is aligned at the
41   predetermined position using the positioning means, the second
42   housing 2 is mounted on the first housing 1 using screws 6 or the

1   like (see FIG. 2). Next, in the state that the second housing 2 is
2   mounted on the first housing 1, the steering shaft supporting
3   sections 10 and 20 having cylindrical shapes and the output shaft
4   supporting sections 11 and 21 having cylindrical shapes are formed
5   in the first and second housings 1 and 2, respectively, by process.
6   More specifically, the positioning of the mounting position of
7   the second housing 2 with respect to the first housing 1 is carried
8   out using the two pins 5a and 5b (positioning means) and the two
9   sets of pin holes 12a, 22a, 12b and 22b (positioning means). In other
10   words, by the engagement of the two pins 5a and 5b, tapered pins or
11   the like, with the two sets of pin holes 12a, 22a, 12b and 22b,
12   tapered holes, respectively provided in the first housing 1 and the
13   second housing 2, the mounting position of the second housing 2
14   with respect to the first housing 1 is aligned at the predetermined
15   position that is determined using the pins 5a and 5b and the pin
16   holes 12a, 22a, 12b and 22b. Next, for the purpose of providing the
17   steering shaft supporting sections 10 and 20 and the output shaft
18   supporting sections 11 and 21 in the first and second housings 1 and
19   2, the second housing 2 is mounted on the first housing 1 using the
20   screws 6 or the like, in the state that the mounting position of the
21   second housing 2 with respect to the first housing 1 is aligned at the
22   predetermined position, the steering shaft supporting section 10 for
23   supporting the steering shaft 3 on the first housing 1 via the bearing
24   7 and the steering shaft supporting section 20 for supporting the
25   steering shaft 3 on the second housing 2 via the bearing 8 are
26   formed in the first housing 1 and the second housing 2, respectively,
27   in one process; furthermore, similarly, the output shaft supporting
28   section 11 for supporting the output shaft 4 on the first housing 1
29   via the bearing 9a and the output shaft supporting section 21 for
30   supporting the output shaft 4 on the second housing 2 via the
31   bearing 9b are formed in the first housing 1 and the second housing
32   2, respectively, in one process.
33   The two sets of pin holes 12a, 22a, 12b and 22b are formed by
34   aligning the second housing 2 with the first housing 1 at an
35   appropriate position, by temporarily securing them using the screws
36   6 or the like, and by making holes in the first and second housings 1
37   and 2 being in the secured state using a drill or the like.
38   The steering shaft supporting section 10 of the first housing 1
39   is a cylindrical portion in which the bearing 7 for supporting the
40   steering shaft 3 is mounted, and the steering shaft supporting
41   section 20 of the second housing 2 is a cylindrical portion in which
42   the bearing 8 for supporting the steering shaft 3 is mounted. The

output shaft supporting section 11 of the first housing 1 is a
cylindrical portion in which the bearing 9a for supporting the output
shaft 4 is mounted, and the output shaft supporting section 21 of the
second housing 2 is a cylindrical portion in which the bearing 9b for
supporting the output shaft 4 is mounted.

FIGS. 4(a) and 4(b) are sectional views of the main sections
schematically showing processes for supporting the steering shaft 3
and the output shaft 4 using the steering shaft supporting sections
10 and 20 and the output shaft supporting sections 11 and 21 via the
bearings 7, 8, 9a and 9b. The lower view is a sectional view taken on
line IV-IV of the upper view.

First, for the purpose of accommodating the steering shaft 3
and the output shaft 4 in the first and second housings 1 and 2, the
two pins 5a and 5b and the screws 6 are removed, and the second
housing 2 is removed temporarily from the first housing 1. Next, the
steering shaft 3 and the output shaft 4 are accommodated in the
first housing 1 and the second housing 2 while being supported
using the steering shaft supporting sections 10 and 20 and the
output shaft supporting sections 11 and 21 via the bearings 7, 8, 9a
and 9b.

More specifically, the two bearings 9a and 9b are pressure-
fitted on the root and the end of the output shaft 4, and the main
body of the motor 41 is mounted in the first housing 1. Similarly,
the large gear 30 and the two bearings 7 and 8 disposed so as to hold
the large gear 30 therebetween are pressure-fitted on the steering
shaft 3, and the steering shaft 3 is accommodated in the first
housing 1. After the accommodation, the second housing 2 is aligned
with the first housing 1, whereby the steering shaft 3 is supported
using the steering shaft supporting section 10 of the first housing 1
via the bearing 7 and also supported using the steering shaft
supporting section 20 of the second housing 2 via the bearing 8.
Similarly, the output shaft 4 is supported using the output shaft
supporting section 11 of the first housing 1 via the bearing 9a and
also supported using the output shaft supporting section 21 of the
second housing 2 via the bearing 9b.

When the steering shaft 3 and the output shaft 4 are
supported using the steering shaft supporting sections 10 and 20
and the output shaft supporting sections 11 and 21, it is preferable
that the bearings 7, 8, 9a and 9b are pressurized in the axial
direction so that the internal clearances in the bearings 7, 8, 9a and
9b are negative radial internal clearances. This can eliminate
rattling between the steering shaft 3 and the bearings 7 and 8 and

1 between the output shaft 4 and the bearings 9a and 9b.

2 FIGS. 5(a) and 5(b) are sectional views of the main sections
3 schematically showing processes for aligning the second housing 2
4 with the first housing 1 at the predetermined position using the
5 positioning means and for mounting the second housing 2. The
6 lower view is a sectional view taken on line V-V of the upper view.

7 The second housing 2 is aligned with the first housing 1, and
8 the two pins 5a and 5b are engaged with the two sets of pin holes
9 12a, 22a, 12b and 22b provided in the first and second housings 1
10 and 2, whereby the mounting position of the second housing 2 with
11 respect to the first housing 1 is determined at the predetermined
12 position. The predetermined position is the same as the
13 predetermined position at which the second housing 2 is mounted on
14 the first housing 1 when the steering shaft supporting sections 10
15 and 20 and the output shaft supporting sections 11 and 21 are
16 provided. In this state, the second housing 2 is mounted on the first
17 housing 1 using the screws 6 (see FIG. 2). Furthermore, the main
18 body of the motor 41 is also accommodated in the first housing 1
19 using screws (not shown) or the like.

20 In the electric power steering apparatus being produced using
21 this method, the second housing 2 is aligned with the first housing 1
22 at the predetermined position and mounted thereon; in the
23 mounting state, the steering shaft supporting sections 10 and 20 and
24 the output shaft supporting sections 11 and 21 are processed; the
25 second housing 2 is temporarily removed from the first housing 1;
26 after the steering shaft 3 and the output shaft 4 are accommodated
27 in the first and second housings 1 and 2, the second housing 2 is
28 aligned again with the first housing 1 at the predetermined position
29 and mounted thereon; hence, the center distance between the
30 steering shaft 3 and the output shaft 4, that is, the center distance
31 between the large gear 30 and the small gear 40, is constant in the
32 range of the dimensional errors of the supporting sections 10, 20, 11
33 and 21 and the bearings 7, 8, 9a and 9b. For this reason, the gear
34 strength and appropriate backlash assumed in the design of the
35 gears can be obtained securely.

36 In addition, in this embodiment, because the steering shaft 3
37 and the output shaft 4 are supported using the steering shaft
38 supporting sections 10 and 20 and the output shaft supporting
39 sections 11 and 21 via the bearings 7, 8, 9a and 9b, even if the
40 electric power steering apparatus is used for a long time, the above-
41 mentioned gear strength and backlash can be obtained securely.

42 Furthermore, in this embodiment, because the mounting

1   position of the first housing 1 with respect to the second housing 2 is
2   determined by engaging the two pins 5a and 5b with the two sets of
3   pin holes 12a, 22a, 12b and 22b provided in the first and second
4   housings 1 and 2, respectively, the positioning can be carried out
5   easily with high position accuracy. In other words, the mounting
6   position of the second housing 2 with respect to the first housing 1
7   can be aligned at the predetermined position in the range of the
8   dimensional errors of the two sets of pin holes 12a, 22a, 12b and 22b
9   and the two pins 5a and 5b. Hence, the center distance between the
10   small gear 40 and the large gear 30 can be made constant with high
11   position accuracy.
12   Moreover, in this embodiment, because tapered holes are used
13   as the two sets of pin holes 12a, 22a, 12b and 22b, and because
14   tapered pins are used as the two pins 5a and 5b, the second housing
15   2 can be positioned on the first housing 1 at the predetermined
16   position, regardless of the dimensional errors of the two sets of pin
17   holes 12a, 22a, 12b and 22b and the two pins 5a and 5b.
18   In this embodiment, although tapered holes and tapered pins
19   are used as the two sets of pin holes and the two pins, it is needless
20   to say that the two sets of pin holes and the two pins are not limited
21   to these, but parallel holes and parallel pins and the like may also
22   be used. In this case, it is preferable that transition fit should be
23   used for the fitting between the parallel holes and the parallel pins.
24   By the use of the transition fit, the positioning can be carried out
25   with high position accuracy in comparison with clearance fit.
26   Still further, in this embodiment, bearings with ordinary
27   cylindrical bores are used; however, without being limited to these,
28   bearings with tapered bores may also be used. In the case that the
29   bearings with tapered bores are used, the steering shaft and the
30   output shaft can be supported using the steering shaft supporting
31   sections and the output shaft supporting sections at more accurate
32   positions.
33   (Embodiment 2)
34   In an electric power steering apparatus, helical gears will be
35   described, in which one set of gears is used, and the large gear
36   thereof is made as small as possible while the speed reduction ratio
37   required for assisting steering operation is maintained and while the
38   gear strength applicable to practical use can be obtained securely.
39   Except for the large gear and the small gear, the configuration and
40   the production method are similar to those of Embodiment 1.
41   The electric power steering apparatus comprises a large gear
42   mounted on the steering shaft 3 and a small gear 40 ~~140~~ mounted on

1 the output shaft 4 of the motor 41, and the large gear and the small
2 gear 40 ~~140~~ are ~~configured as~~ spur gears or helical gears configured
3 as involute gears. By the use of the spur gears or the helical gears,
4 the motor 41 can be disposed so as to be in nearly parallel with the
5 steering shaft 3. However, the outside dimensions of the motor 41
6 are physically restricted in layout depending on the center distance
7 L between the steering shaft 3 and the output shaft 4 of the motor
8 41. For example, because of the restrictions in layout, the maximum
9 allowable outside dimensions of the motor 41 are 80 mm in diameter
10 and 95 mm in height. In this case, for the purpose of securely
11 obtaining a rotary torque of 35 Nm or more as the steering assist
12 torque around the steering shaft, the rated torque is set at 4 Nm, the
13 center distance L is set at 55 mm, and the speed reduction ratio N is
14 set at approximately 10.
15   FIG. 6 is a graph showing the relationship between the
16 number of teeth Z of the small gear 40 ~~140~~ and the module m of the
17 small gear 40 ~~140~~ in the case that the center distance L between the
18 steering shaft 3 and the output shaft 4 of the motor 41 is 55 mm,
19 that the speed reduction ratio N is 10, and that the helix angle β is
20 25 degrees. Although the pitch circle diameter d (= Z × m) of the
21 small gear 40 ~~140~~ is approximately 8 to 10 mm, for the purpose of
22 avoiding states in which the number of teeth is too many or too few,
23 the practically endurable ranges of the number of teeth Z and the
24 module m are 6 or more and 15 or less and 0.8 or more and 1.5 or
25 less, respectively.
26   Next, in consideration of gear production errors and the elastic
27 deformation amounts of the gear teeth in the case that rated load
28 operation is carried out, the pressure angle α is determined so that
29 the trochoid interference clearance and the tooth thickness at the
30 addendum have appropriate values. FIG. 7 is a graph showing the
31 relationship among the pressure angle α, the trochoid interference
32 clearance and the tooth thickness at the addendum of the small gear
33 40 ~~140~~ in the case that the center distance L is 54.7 mm, that the
34 number of teeth Z is 10, that the module m is 0.95 and that the tooth
35 depth h is 2.25 times the module m. The circular marks in FIG. 7
36 indicate trochoid interference clearance values, and the square
37 marks indicate values each obtained by dividing the tooth thickness
38 at the addendum by the module value.
39   For the purpose of avoiding occurrence of trochoid
40 interference, the trochoid interference clearance is required to be 0.2
41 mm or more. As shown in FIG. 7, in the case that the pressure
42 angle α is in the range of 20 degrees or more and 35 degrees or less

1   as specified as standard values in JIS (Japanese Industrial

2   Standard), the trochoid interference clearance is 0.2 mm or more

3   when the pressure angle α is 23 degrees or more, and trochoid

4   interference does not occur. On the other hand, for the purpose of

5   securely obtaining the strength at the addendum, the tooth

6   thickness at the addendum is required to be 0.3 times the module m

7   or more. For the purpose of obtaining the tooth thickness at the

8   addendum being 0.3 times the module m or more, the pressure angle

9   α is required to be 27 degrees or less as shown in FIG. 7. The

10   practical range of the helix angle β is 0 degrees or more and 40

11   degrees or less.

12   In the case that steel is used as the material of the small gear

13   <u>40</u> ~~140~~ and the large gear, the tooth face stress σ_s for the load P_n

14   applied perpendicularly to a tooth of the small gear <u>40,</u> ~~140,~~

15   generated by the assist rotary torque, can be obtained approximately

16   using (Equation 1).

17   [Equation 1]

$$\sigma_s^2 = 0.35 \cdot E \cdot P_n \left[\frac{Z_1 + Z_2}{Z_2} \right] \frac{\cos^2 \beta_g}{\varepsilon_s \cdot b \cdot d_b \cdot \sin \alpha_b}$$

18

19   In (Equation 1), E designates the longitudinal elastic modulus

20   of the material of the gear (steel in this embodiment), ε_s designates

21   the transverse contact ratio of the gear, b designates the tooth width

22   of the small gear <u>40,</u> ~~140,~~ d_b designates the meshing pitch circle

23   diameter of the small gear <u>40,</u> ~~140,~~ α_b designates the meshing

24   pressure angle of the small gear <u>40,</u> ~~140,~~ β_g designates the

25   cylindrical helix angle of the base circle of the small gear <u>40,</u> ~~140,~~ Z_1

26   designates the number of teeth of the small gear <u>40,</u> ~~140,~~ and Z_2

27   designates the number of teeth of the large gear.

28   FIG. 8 is a graph showing the relationship of the tooth face

29   stress σ_s and the tooth thickness at addendum depending on the

30   tooth depth h of the small gear <u>40</u> ~~140~~ in the case that E is 206000

31   N/mm^2, P_n is 946 N, b is 14 mm, Z_1 is 10, Z_2 is 97, m is 0.95, the

32   pressure angle α is 25 degrees, the helix angle β is 25 degrees, d_b is

33   10.225 mm, α_b is 25.063 degrees, and β_g is 21.631 degrees in

34   (Equation 1). The circular marks in FIG. 8 indicate tooth face stress

35   values, and the square marks indicate values each obtained by

36   dividing the tooth thickness at the addendum by the module value.

37   In the case that the target value of the tooth face stress σ_s is

38   the threshold value of 1760 N/mm^2 or less in the design of the power

39   transmission gear of an automobile and that the target value of the

1 tooth thickness at the addendum is 0.3 times the module m or more,
2 both the conditions can be satisfied simultaneously in the case that
3 the tooth depth h is 2.4 times the module m or less, as shown clearly
4 in FIG. 8.
5   FIG. 9 is an explanatory view showing the tooth face profile of
6 a gear being used for the electric power steering apparatus according
7 to the embodiments of the present invention. For the purpose of
8 compensating for the lowering of the strength at the deddendum, the
9 tooth face profile of either one of the large gear and the small gear
10 140 or both of the gears used as a pair is formed as shown in FIG. 9.
11 In FIG. 9, the tooth face of the small gear 140 is divided in a mesh
12 pattern in the lengthwise and crosswise directions. In the tooth
13 profile direction, a negative pressure angle error is provided so that
14 the pressure angle at the deddendum is larger than the pressure
15 angle at the addendum, and the tooth face profile is formed in a
16 direction such that the mutual meshing stress increases, that is,
17 such that the central portion thereof has a convex shape. In
18 addition, crowning is carried out in the tooth trace direction and the
19 central portion thereof also is formed to have a convex shape in the
20 tooth trace direction.
21   With the tooth face profile described above, the distribution of
22 the contact stress on the tooth face of the small gear 140 can be
23 made even in the tooth profile direction and the tooth trace
24 direction, thereby capable of preventing partial abrasion on the
25 tooth face, compensating for the insufficient strength at the
26 deddendum, and contributing to improvement in durability.
27   Furthermore, because the small gear or 140 and the large gear
28 having the tooth face profile described above are mounted using the
29 production method described in Embodiment 1, the center distance
30 between the large gear and the small gear 140 can be maintained
31 constant accurately, and the gear strength assumed in the design of
32 the gear can be obtained securely.
33